

CLAIMS

What is claimed is:

1. A method for collecting garbage in a computing environment, the method
5 comprising:
 - a) tracing a root object to any of its reachable objects in a population of objects;
 - b) marking any of said objects referred to in step a);
 - c) unmarking a marked card comprising any of said objects;
 - 10 d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
 - e) marking said unmarked referent object;
 - f) tracing said referent object marked in step e) to any of its reachable objects;
 - 15 g) marking any of said objects referred to in step f);
 - h) tracing any unmarked root object referent to any of its reachable objects;
 - i) marking any of said objects referred to in step h);
 - j) performing any of steps c) – g); and
 - 20 k) designating any unmarked object in said population of objects as available for reallocation,

wherein any of steps a) – g) are performed upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of steps h) – k) are performed upon said
25 population of objects while no mutator operates upon said population of objects within said computing environment.
2. A method according to claim 1 and further comprising marking said card if said mutator modifies an object pointer of an object in said card.
- 30 3. A method according to claim 1 wherein any of steps a) – g) are performed concurrently.

4. A method according to claim 1 wherein any of steps h) – j) are performed concurrently.
5. A method according to claim 1 wherein either of steps a) and f) are performed for a given object only if the card to which the object belongs is not marked.
6. A method according to claim 1 and further comprising marking said card only if there is at least one marked object already on said card.
- 10 7. A method according to claim 1 and further comprising periodically unmarking any marked card that does not contain at least one of said marked objects.
8. A method according to claim 1 and further comprising:
designating any of said objects as “new”; and
15 deferring the tracing of said “new” objects during any cycle of a plurality of cycles during which any of steps a) – g) are performed.
9. A method according to claim 8 wherein said designating as “new” step is performed if said object is part of an allocation cache from which objects are currently
20 being allocated.
10. A method according to claim 8 and further comprising:
periodically unmarking any marked card containing only “new” objects; and
removing said “new” objects’ “new” designation.
- 25 11. A method according to claim 10 wherein said periodically unmarking and removing steps are performed if said object is part of an allocation cache from which objects are not currently being allocated.
- 30 12. A method for collecting garbage in a computing environment, the method comprising:

- a) tracing a root object to any of its reachable objects in a population of objects;
- b) marking any of said objects referred to in step a);
- c) unmarking a marked card comprising any of said objects;
- 5 d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
- e) marking said unmarked referent object;
- f) tracing said referent object marked in step e) to any of its reachable objects;
- 10 g) marking any of said objects referred to in step f);
- h) tracing any unmarked root object referent to any of its reachable objects;
- i) marking any of said objects referred to in step h);
- j) performing any of steps c) – g); and
- 15 k) designating any unmarked object in said population of objects as available for reallocation,

wherein either of steps a) and f) are performed for a given object only if the card to which the object belongs is not marked, wherein any of steps a) – g) are performed upon said population of objects concurrently with the operation of a mutator

20 upon said population of objects within said computing environment, and wherein any of steps h) – k) are performed upon said population of objects while no mutator operates upon said population of objects within said computing environment.

13. A method according to claim 12 and further comprising marking said card if

25 said mutator modifies an object pointer of an object in said card.

14. A method according to claim 12 wherein any of steps a) – g) are performed concurrently.

30 15. A method according to claim 12 wherein any of steps h) – j) are performed concurrently.

16. A method for collecting garbage in a computing environment, the method comprising:

a) tracing a root object to any of its reachable objects in a population of objects;

5 b) marking any of said objects referred to in step a);

c) unmarking a marked card comprising any of said objects;

d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;

e) marking said unmarked referent object;

10 f) tracing said referent object marked in step e) to any of its reachable objects;

g) marking any of said objects referred to in step f);

h) tracing any unmarked root object referent to any of its reachable objects;

15 i) marking any of said objects referred to in step h);

j) performing any of steps c) – g); and

k) designating any unmarked object in said population of objects as available for reallocation,

wherein prior to said unmarking step c) said card is marked only if there is
20 at least one marked object already on said card, wherein any of steps a) – g) are performed upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of steps h) – k) are performed upon said population of objects while no mutator operates upon said population of objects within said computing environment.

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17. A method according to claim 16 and further comprising marking said card if said mutator modifies an object pointer of an object in said card.

18. A method according to claim 16 wherein any of steps a) – g) are performed
30 concurrently.

19. A method according to claim 16 wherein any of steps h) – j) are performed concurrently.
20. A method for collecting garbage in a computing environment, the method
5 comprising:
- a) tracing a root object to any of its reachable objects in a population of objects;
 - b) marking any of said objects referred to in step a);
 - c) unmarking a marked card comprising any of said objects;
 - 10 d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
 - e) marking said unmarked referent object;
 - f) tracing said referent object marked in step e) to any of its reachable objects;
 - 15 g) marking any of said objects referred to in step f);
 - h) tracing any unmarked root object referent to any of its reachable objects;
 - i) marking any of said objects referred to in step h);
 - j) performing any of steps c) – g);
 - 20 k) designating any unmarked object in said population of objects as available for reallocation; and
 - l) prior to performing any of steps a) – g), periodically unmarking any marked card that does not contain at least one of said marked objects,
- wherein any of steps a) – g) are performed upon said population of objects
25 concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of steps h) – k) are performed upon said population of objects while no mutator operates upon said population of objects within said computing environment.
- 30 21. A method according to claim 20 and further comprising marking said card if said mutator modifies an object pointer of an object in said card.

22. A method according to claim 20 wherein any of steps a) – g) are performed concurrently.
23. A method according to claim 20 wherein any of steps h) – j) are performed
5 concurrently.
24. A method for collecting garbage in a computing environment, the method comprising:
- 10 a) tracing a root object to any of its reachable objects in a population of objects;
- b) marking any of said objects referred to in step a);
- c) unmarking a marked card comprising any of said objects;
- d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
- 15 e) marking said unmarked referent object;
- f) tracing said referent object marked in step e) to any of its reachable objects;
- g) marking any of said objects referred to in step f);
- h) tracing any unmarked root object referent to any of its reachable
20 objects;
- i) marking any of said objects referred to in step h);
- j) performing any of steps c) – g);
- k) designating any unmarked object in said population of objects as available for reallocation; and
- 25 l) during any cycle of a plurality of cycles during which steps a) – g) are performed:
- designating any of said objects as “new”; and
- deferring the tracing of said “new” objects,
- wherein any of steps a) – g) are performed upon said population of objects
- 30 concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of steps h) – k) are performed upon said

population of objects while no mutator operates upon said population of objects within said computing environment.

25. A method according to claim 24 and further comprising marking said card if
5 said mutator modifies an object pointer of an object in said card.

26. A method according to claim 24 wherein any of steps a) – g) are performed concurrently.

10 27. A method according to claim 24 wherein any of steps h) – j) are performed concurrently.

28. A method according to claim 24 wherein said designating as “new” step is performed if said object is part of an allocation cache from which objects are currently
15 being allocated.

29. A method according to claim 24 and further comprising:
periodically unmarking any marked card containing only “new” objects; and
removing said “new” objects’ “new” designation.

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30. A method according to claim 29 wherein said periodically unmarking and removing steps are performed if said object is part of an allocation cache from which objects are not currently being allocated.

25 31. A system for collecting garbage in a computing environment, the system comprising:

- a) means for tracing a root object to any of its reachable objects in a population of objects;
- b) means for marking any of said objects referred to in a);
- 30 c) means for unmarking a marked card comprising any of said objects;
- d) means for tracing any marked object on said unmarked card to an unmarked referent object of said marked object;

- e) means for marking said unmarked referent object;
- f) means for tracing said marked referent object marked in e) to any of its reachable objects;
- g) means for marking any of said objects referred to in f);
- 5 h) means for tracing any unmarked root object referent to any of its reachable objects;
- i) means for marking any of said objects referred to in h); and
- j) means for designating any unmarked object in said population of objects as available for reallocation,
- 10 wherein any of means a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of means h) – j) operate upon said population of objects while no mutator operates upon said population of objects within said computing environment.
- 15 32. A system according to claim 31 and further comprising means for marking said card if said mutator modifies an object pointer of an object in said card.
- 33. A system according to claim 31 wherein any of means a) – g) operate
20 concurrently.
- 34. A system according to claim 31 wherein any of means h) – i) operate concurrently.
- 25 35. A system according to claim 31 wherein either of tracing means a) and f) are operative to trace a given object only if the card to which the object belongs is not marked.
- 36. A system according to claim 31 and further comprising means for marking
30 said card only if there is at least one marked object already on said card.

37. A system according to claim 31 and further comprising means for periodically unmarking any marked card that does not contain at least one of said marked objects.
- 5 38. A system according to claim 31 and further comprising:
means for designating any of said objects as “new”; and
means for deferring the tracing of said “new” objects during any cycle of a plurality of cycles during which any of means a) – g) operate.
- 10 39. A system according to claim 38 wherein said means for designating as “new” is operative if said object is part of an allocation cache from which objects are currently being allocated.
40. A system according to claim 38 and further comprising:
15 means for periodically unmarking any marked card containing only “new” objects; and
means for removing said “new” objects’ “new” designation.
41. A system according to claim 40 wherein said means for periodically
20 unmarking and said means for removing are operative if said object is part of an allocation cache from which objects are not currently being allocated.
42. A system for collecting garbage in a computing environment, the system comprising:
25 a) means for tracing a root object to any of its reachable objects in a population of objects;
b) means for marking any of said objects referred to in a);
c) means for unmarking a marked card comprising any of said objects;
d) tracing any marked object on said unmarked card to an unmarked
30 referent object of said marked object;
e) marking said unmarked referent object;

- f) means for tracing said marked referent object in e) to any of its reachable objects;
- g) means for marking any of said objects referred to in f);
- h) means for tracing any unmarked root object referent to any of its
- 5 reachable objects;
- i) means for marking any of said objects referred to in h); and
- j) means for designating any unmarked object in said population of objects as available for reallocation,
- wherein either of tracing means a) and f) trace a given object only if the card
- 10 to which the object belongs is not marked, wherein any of means a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of means h) – j) operate upon said population of objects while no mutator operates upon said population of objects within said computing environment.
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43. A system for collecting garbage in a computing environment, the system comprising:
- a garbage collector comprising:
- a) means for tracing a root object to any of its reachable objects in a
- 20 population of objects;
- b) means for marking any of said objects referred to in a);
- c) means for unmarking a marked card comprising any of said objects;
- d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
- 25 e) marking said unmarked referent object;
- f) means for tracing said marked referent object in e) to any of its reachable objects;
- g) means for marking any of said objects referred to in f);
- h) means for tracing any unmarked root object referent to any of its
- 30 reachable objects;
- i) means for marking any of said objects referred to in h); and

j) means for designating any unmarked object in said population of objects as available for reallocation; and

a mutator operative to mark said card only if there is at least one marked object already on said card,

5 wherein any of means a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of means h) – j) operate upon said population of objects while no mutator operates upon said population of objects within said computing environment.

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44. A system for collecting garbage in a computing environment, the system comprising:

a) means for tracing a root object to any of its reachable objects in a population of objects;

15 b) means for marking any of said objects referred to in a);

c) means for unmarking a marked card comprising any of said objects;

d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;

e) marking said unmarked referent object;

20 f) means for tracing said marked referent object in e) to any of its reachable objects;

g) means for marking any of said objects referred to in f);

h) means for tracing any unmarked root object referent to any of its reachable objects;

25 i) means for marking any of said objects referred to in h);

j) means for designating any unmarked object in said population of objects as available for reallocation; and

k) means for periodically unmarking any marked card that does not contain at least one of said marked objects,

30 wherein any of means a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects within said computing environment, and wherein any of means h) – j) operate upon said population

of objects while no mutator operates upon said population of objects within said computing environment.

45. A system for collecting garbage in a computing environment, the system
5 comprising:

- a) means for tracing a root object to any of its reachable objects in a population of objects;
 - b) means for marking any of said objects referred to in a);
 - c) means for unmarking a marked card comprising any of said objects;
 - 10 d) tracing any marked object on said unmarked card to an unmarked referent object of said marked object;
 - e) marking said unmarked referent object;
 - f) means for tracing said marked referent object in e) to any of its reachable objects;
 - 15 g) means for marking any of said objects referred to in f);
 - h) means for tracing any unmarked root object referent to any of its reachable objects;
 - i) means for marking any of said objects referred to in h);
 - j) means for designating any unmarked object in said population of
20 objects as available for reallocation;
 - k) means for designating any of said objects as “new”; and
 - l) means for deferring the tracing of said “new” objects,
- wherein any of means a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects within said
25 computing environment, and wherein any of means h) – j) operate upon said population of objects while no mutator operates upon said population of objects within said computing environment.

46. A computer program embodied on a computer-readable medium, the
30 computer program comprising:

- a) a first code segment operative to trace a root object to any of its reachable objects in a population of objects;

- b) a second code segment operative to mark any of said objects referred to in a);
- c) a third code segment operative to unmark a marked card comprise any of said objects;
- 5 d) a fourth code segment operative to trace any marked object on said unmarked card to an unmarked referent object of said marked object;
- e) a fifth code segment operative to mark said unmarked referent object;
- f) a sixth code segment operative to trace said marked referent object in e) to any of its reachable objects;
- 10 g) a seventh code segment operative to mark any of said objects referred to in f);
- h) a eighth code segment operative to trace any unmarked root object referent to any of its reachable objects;
- i) a ninth code segment operative to mark any of said objects referred to
- 15 in h); and
- j) a tenth code segment operative to designate any unmarked object in said population of objects as available for reallocation,
- wherein any of code segments a) – g) operate upon said population of objects concurrently with the operation of a mutator upon said population of objects
- 20 within said computing environment, and wherein any of code segments h) – k) operate upon said population of objects while no mutator operates upon said population of objects within said computing environment.

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